Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Detailed load simulation for better grid planning

To cite this article: Noah Pflugradt and Urs Muntwyler 2019 *J. Phys.: Conf. Ser.* **1343** 012048

Detailed load simulation for better grid planning

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Abstract. The future load profile is the single most important factor for determining the future grid. But in many cases while planning future grids, the planners simply assume that the future load will be much like the current one, which can cause large problems later. In this paper an alternative approach is shown. For the research project “SimZukunft” the future load is calculated based on the official scenarios for Switzerland, which are broken down to the level of the individual house. A bottom-up simulation is used to calculate the future load profile, which is then used to perform the grid planning. The paper explains the methods used to generate a detailed bottom up model for a city as well as the challenges and benefits of the approach and gives a brief overview of some of the results of the research project.

1. Introduction

Switzerland adopted the Energy Strategy 2050 (ES2050) in 2017. This strategy is based on a detailed study for the entire country by Prognos [1]. It does not investigate the consequences of these developments for the low voltage grids in detail though. The project “SimZukunft” aims to answer what the ES2050 will mean for the low voltage grids in small to medium towns using detailed load simulation and data analysis. As example the Swiss city “Burgdorf” will be used. It has 16.000 residents.

The aim of the project is not only to evaluate Burgdorf though. The overarching goal of the project is to demonstrate the benefits of a detailed, bottom up, future load analysis. For this, different scenarios from the ES2050 will be applied to the energy consumption in Burgdorf and grid calculations will be performed that will show the consequences of these scenarios on the grid. The project is not finished yet, thus not all results can be presented yet.

2. Scenarios

In the original study [1] from 2012 three different scenarios with three variants each for a total of nine cases were described. Most of these cases are now obsolete the ES2050 has been officially adtoped in Switzerland in the year 2017. In the research project two of the non-obsolete cases are evaluated. Additionally, two extreme scenarios were created to provide a stress test of the grid. The scenarios used in the project are shown in **Table 1**. By having a comparison of the effects of all smart grid technologies vs. no smart grid technology at all it is possible to calculate an upper bound for the impact of all smart grid technologies.

Table 1: Scenarios used in the project

Scenario Name	Description
"ES2050 – Political Measures"	This is the path Switzerland is currently pursuing. It includes medium amounts of renewable energy, medium amounts of renewable energy and phases out nuclear energy.
"ES2050 – Political Measures – Smart"	This scenario is identical to the previous, but for the purpose of the grid planning, we are assuming maximum smart grid technology deployment, such as intelligent heat pump control, intelligent electric vehicle charging, optimal photovoltaic curtailment and decentralized energy storage to minimize grid expansion cost.
"ES2050 – New Energy Politics"	This scenario is a slightly more aggressive variant of the political measures, with a higher percentage of renewable energy, higher building renovation rates and less CO2 total.
"Utopia"	To see where the limits of the renewable energy in the grid are, this scenario assumes maximum PV adoption, full conversion to electric vehicles, switching all heating systems to heat pumps, full renovation of all buildings and much more.
"Dystopia"	This scenario aims to model the consequences of a big increase in consumption without much local renewable energy generation.

3. Method

The approach used in the project is shown in **Figure 1**. The first step was building a consistent model of the current situation in Burgdorf. The data sources used are the utility data, statistical data, the Swiss building database and more. Merging these different data sets proved to be rather challenging though, due to the complexity of the real world and that not all data which would have been useful was available.

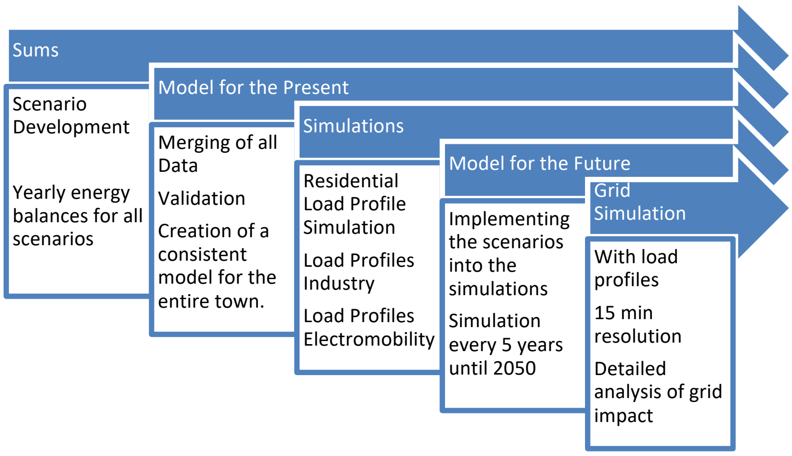

Figure 1: Project plan

3.1. General Scripting Strategy

For developing the scripts to build up the database of the current situation, it paid off to split the task in a lot of small, discrete and easily debuggable steps that are all additive and never modify the source data. For example, instead of writing a function that fixes spelling mistakes in the street names in the source data, a function was used that wrote the new, fixed street names into a new column. This way it is possible to start over at each step in the process if any bugs are discovered and run from this step onward, dramatically improving maintainability of the scripts. Another thing that proved to be very helpful while developing the scripts was to have every single step produce some results charts that show the results of the step. For example, the script to allocate the cars to the households produces a map of the city that shows exactly where the cars are allocated.

3.2. Model for the present
What is needed to perform the calculations for the future load profiles is a database that shows for every single building in the city, how many households are in the building, how many people are living in each household, how much energy they use, if they are employed, if they have any cars, if they commute to work in their car, if there are any businesses and much more. But at lot of this data is not actually available at this level of detail. Instead information such as the total number of cars in the city is available. For example, the statistics might say that there are 3 people commuting from Zurich every day and our model will have indeed three people doing this. But since it isn't known exactly where they live, these people are randomly allocated to households. So the end result is a model of the city that matches all available data about reality, but might not match reality in every detail, which is a subtle, but important distinction. But only by lowering the requirements to this the project is possible at all.

For the aspects where only aggregated data is available, heuristics were developed to generate a model that is as accurate as possible. For example, for allocating the number of people to the households, a fuzzy logic algorithm was used that estimated based on the energy use in the apartment and the total floor area how many people might live in each apartment. Then the parameters of the fuzzy logic decision boundaries were tuned until both the total number of households and the number of citizens matched the official statistics.

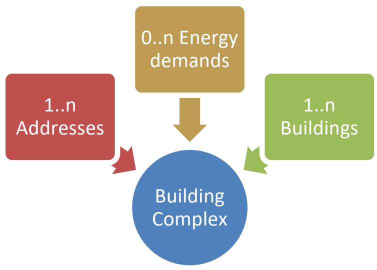

Figure 2 : Data model for Building Complexes

A special challenge was dealing with the complexity of the real world. Not every house has exactly one power connection and not every house has exactly one address. Instead bigger buildings sometimes have multiple addresses, multi-tenant-houses might have many different energy meters, industry campuses can have multiple building using a single address and supplied by a single power meter and so on. To deal with this complex situation it turned out to be a good idea to create virtual building complexes. The simplest case of such a building complex is a single-family house with exactly one address and one energy meter. But also, an industry campus with multiple meters, multiple addresses and multiple buildings might be a single building complex if all the entities are connected. The advantage of introducing this concept is the possibility of automatically delimiting the individual building complexes and calculating average energy consumptions per square meter, which gives important information about the current state of the building and the potential for reductions in energy demand.

3.3. Future Scenarios
For calculating the future, the scripts take the database of the current situation and then applies modifications for every year based on target values from the scenarios. Thus the database has information for every single house about how many people are living in the house, what their age is, how many cars they have, how far they travel to work, if they have a PV-System, how big it is, and so on.

In the project the load profile for every single building is calculated for every building for every 5 years between 2020 and 2050. The residential load profiles are generated using the LoadProfileGenerator (LPG) [2], a behavior-based agent simulation. The LPG models the individual residents as independent, desire-driven software-agents and is thus able to generate very detailed activity profiles and load profiles. Because of the special modelling approach the LPG is also able to generate electricity charging profiles for the cases where there is an electric vehicle used in the household. Industrial profiles for large customers are based on the current, measured profiles and modified by applying appropriate factors from the ES2050. For smaller businesses standardized load profiles are used.

Heating profiles for heat pump demand are generated using a heating degree model where the yearly totals are set based on the scenario and current heating demands. This way individual load profiles for every single future house and business in the city can be generated. Then those profiles are used to model the future electricity use in the low voltage grid in detail. For photovoltaics the generation profiles are generated using NREL SAM. [3] As weather data input the future weather data scenarios from Meteonorm are used. [4]

This way a load profile with a time resolution of 15 minute can be created for every single building in every year in every scenario, which is then used for the grid calculations. For this research project four major sources of change for the future scenarios have been identified. These are described below.

3.3.1. Increasing Photovoltaics

In Switzerland the Swiss Federal Office for Energy decided to do studies that estimate the solar potential of every single building in Switzerland. In the scenario "Utopia" it is assumed that 100% of this potential will be realized. While this might overestimate the potential that can be achieved with the current technology, it seems reasonable for the authors to assume that further increases in efficiency, solar shingles and solar facade systems will more than compensate for this overestimate. The study used an efficiency of 17% for the photovoltaic systems with a performance ratio of 0.8.

3.3.2. Air Conditioning

Given the current rate of climate change it seems likely that there will be more use of air conditioning in the future. The official study agrees and suggests a value of 30 kWh/m2 for all buildings. Scaled to Burgdorf this means a total yearly energy consumption of 13.3 GWh. For **Figure 5** this energy sum was spread over the year using the cooling degree hour method. Interesting are the extremely high peaks especially in the evening hours, if no intelligent control is used. This shows that having some thermal storage and smart grid functionality to reduce the peaks is essential.

3.3.3. Electromobility

For the Utopia scenario it is assumed that all vehicles will be electric. Currently Burgdorf has 7040 vehicles. Using statistical data for Switzerland that works out to about 15 GWh per year assuming a consumption of 20 kWh/100km in each car. This consumption is spread evenly over the year, which works out a base load of 1.7 MW. This assumes that using suitable smart grid methods it will be possible to even out the load spikes.

3.3.4. Heat Pumps

The utopia scenario assumes that 2050 100% of all heating systems are replaced by heat pumps. There are two reasons for this extreme assumption: First, the goal is to evaluate how well the grid copes with extreme loads. Second, there are now the first studies that assume worldwide PV-prices of 1 ct/kWh in 2050 [5]. This would mean that heat pumps powered by PV are the cheapest possible option for heating.

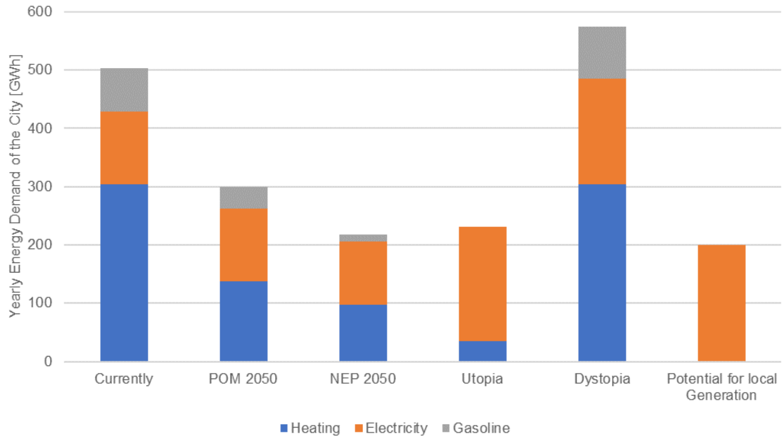

Figure 3 : Total energy consumption of the city in the different scenarios [6]

4. Results

The total energy consumption of each scenario in 2050 is shown in **Figure 3**. It is visible that the total energy use in the future will decrease significantly, but the electricity consumption will increase. This shows that such a detailed bottom-up calculation is invaluable, not only for planning the electricity grid, but also for strategic planning of the entire utility company.

Another interesting first result is the impact of the scenarios on the future load profiles. **Figure 5** shows the changes in the load profile of the entire city for the utopia scenario. It is visible that the impact of the climate change and the increased air conditioning might case higher load peaks than the heat pumps and electromobility combined.

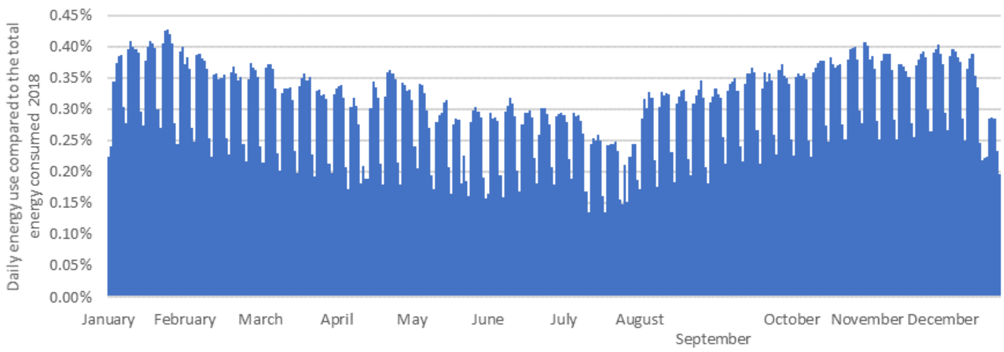

Figure 4 : Current load profile of the city [6]

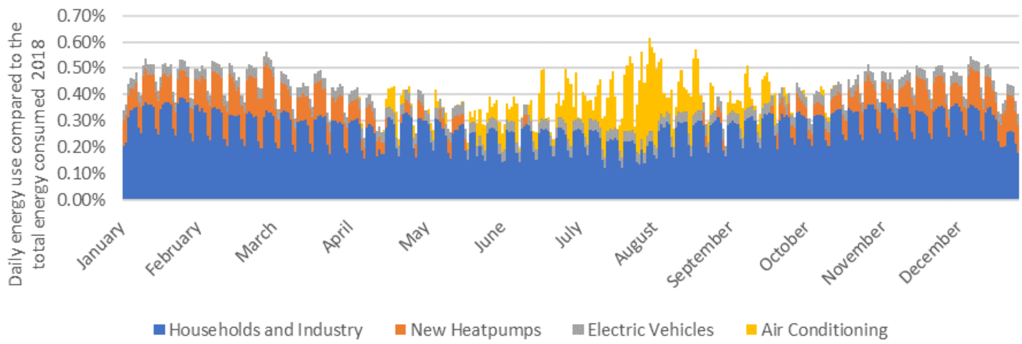

Figure 5 : Future load profile in the utopia scenario [6]

Figure 6 shows the spread of the photovoltaic systems in Burgdorf using the heuristic that bigger systems are more likely to be built first, because they might be more lucrative. The pictures serve to visualize how distributed the future energy will be. It is also shown that even in these extreme scenarios not every building will be covered by PV.

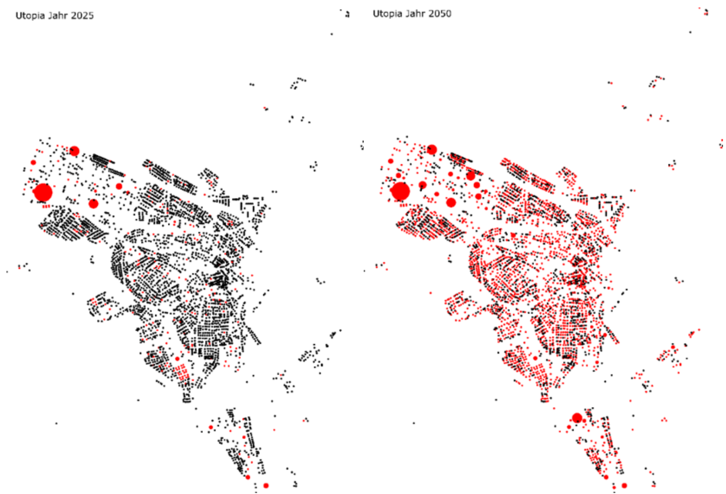

Figure 6 : Spread of PV systems. The size of the circle shows the power of the PV system.

5. Conclusion

The project will be completed at the end of 2019, but the first findings are already interesting. For example, Burgdorf can reach net-zero in the Utopia scenario: This means that the locally generated energy over the year is equal to the total energy demand. Another conclusion is that unless serious investments into grid expansion are performed, in the Utopia scenario major curtailment will be required in the summer.

And despite net-zero and large local energy storage in this scenario, there are weeks in the wintertime where all buffer storages are empty and local generation is negligible. This requires either large investments into power-to-gas technologies or a continued strong uplink to the high voltage grids.

In conclusion, there will be large challenges associated with transforming the energy system. On the one hand fossil fuels will be significantly reduced, but on the other hand additional, large electricity loads will be added. By carefully considering the future situation in a bottom-up approach for all their customers, utilities can limit risk and avoid large stranded investments.

Acknowledgements

This research project is financed by the Swiss Federal Office for Energy (SFOE) and is part of the research activities in the Swiss Centre for Competence in Energy Research on the Future Swiss Electrical Infrastructure (SCCER-FURIES), which is financially supported by the Swiss Innovation Agency (Innosuisse - SCCER program). We also gratefully acknowledge funding from Bern University of Applied Sciences BFH, Burgdorf, Switzerland.

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